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Biofuels from Crop Residue: Soil Organic Carbon and Climate Impacts in the US and India

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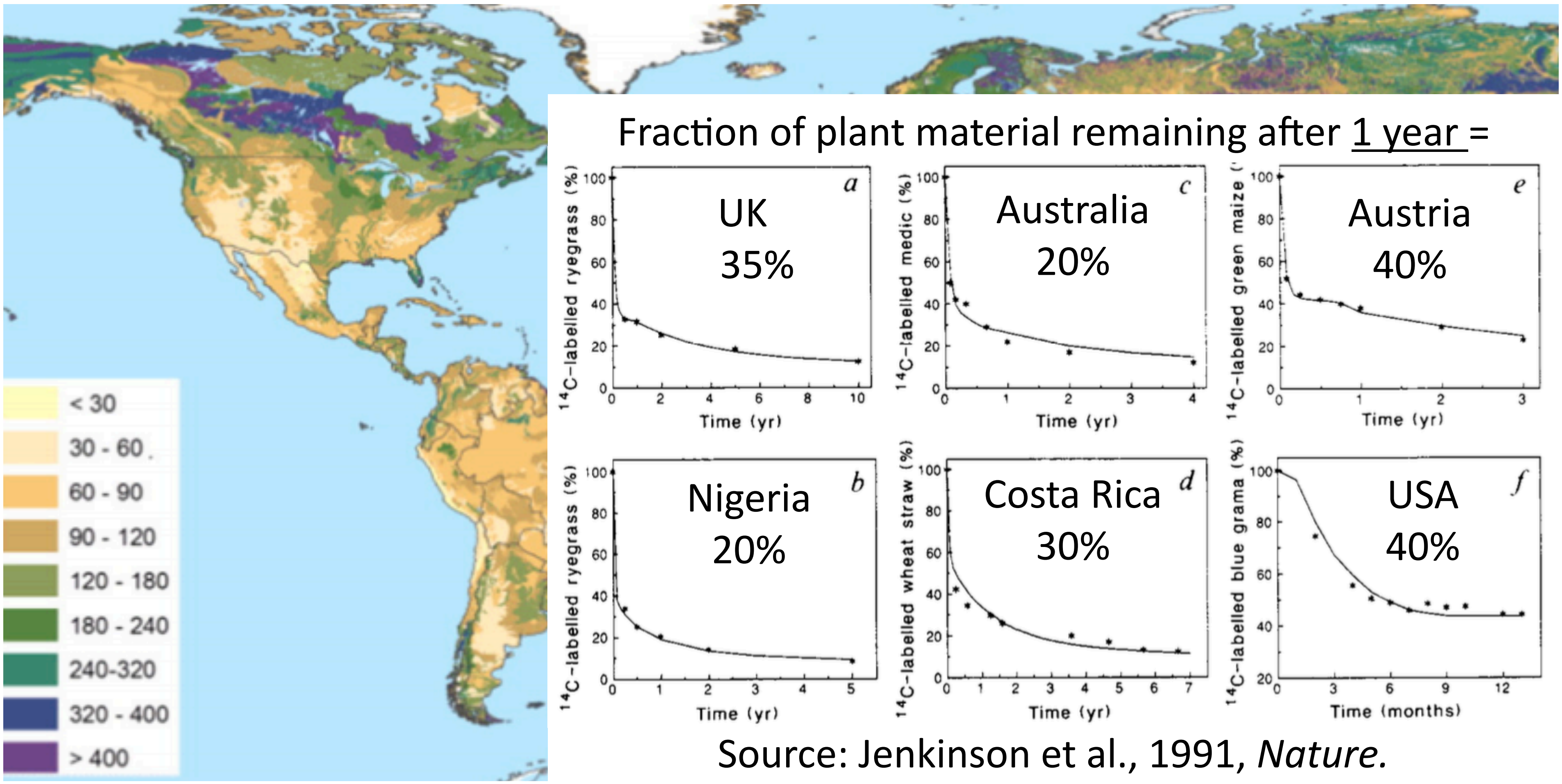
Soil organic carbon (SOC) levels are the balance of carbon inputs from plant material and loss from oxidation to CO_2 ($SOC = I_C - kC_{oc}$) SOC tends to decrease as atmospheric temperature increase

Soil organic carbon content to 1 m depth ($Mg\ C\ ha^{-1}$); Batjes 2016.

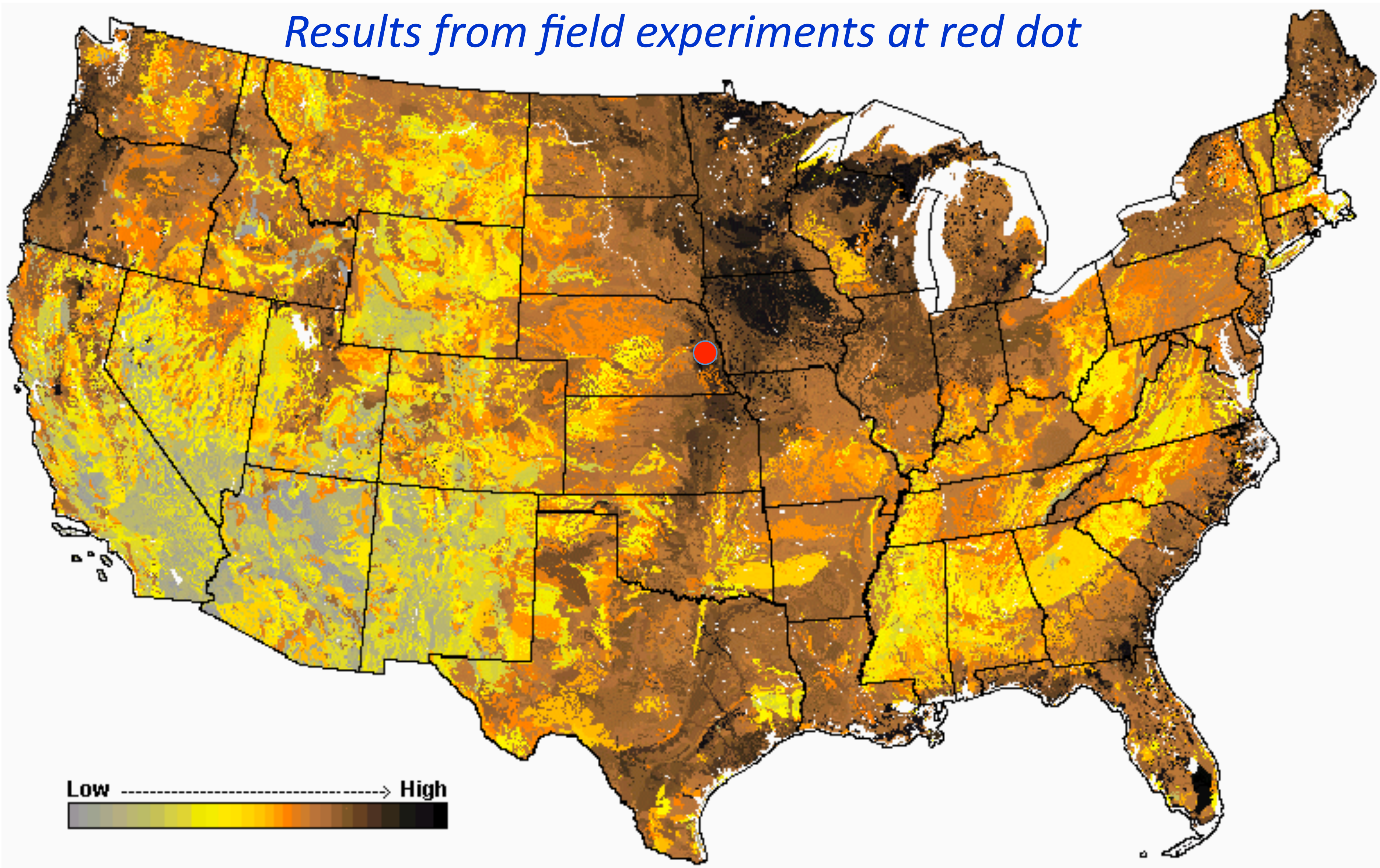


Source: Jenkinson et al., 1991, *Nature.*

Sources: Batjes, 2016, *Geoderma*; Lal & Sanchez, 1992, *Myth & Science of Soils in the Tropics,* Greenland et al. p.17-33; Kutsch et al, 2009, *Soil Carbon Dynamics*, Cambridge.

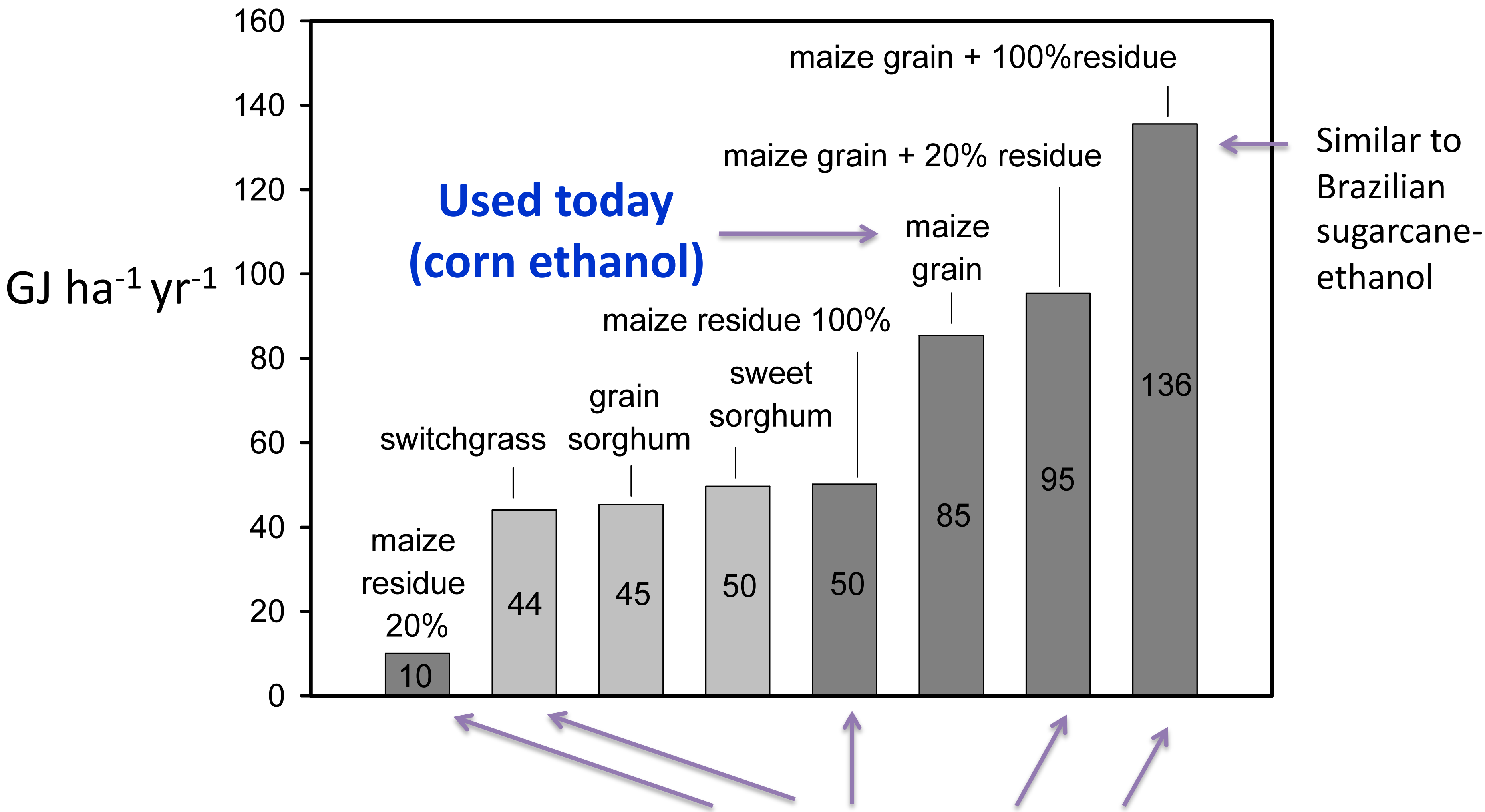
In the US, SOC levels are highest in the north central region (Iowa) where maize & soybean are grown at high yields;

Results from field experiments at red dot



Source: Hargrove and Luxmore 1988; University of Minnesota Extension

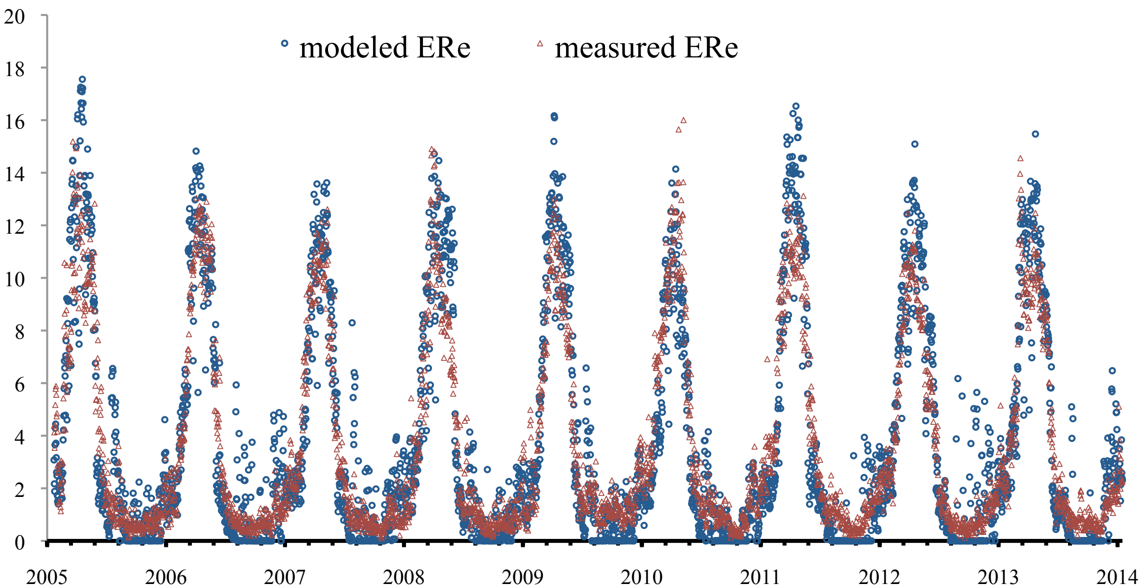
In the US, gross energy yield of biofuel production can be increased by using both maize grain & maize residue

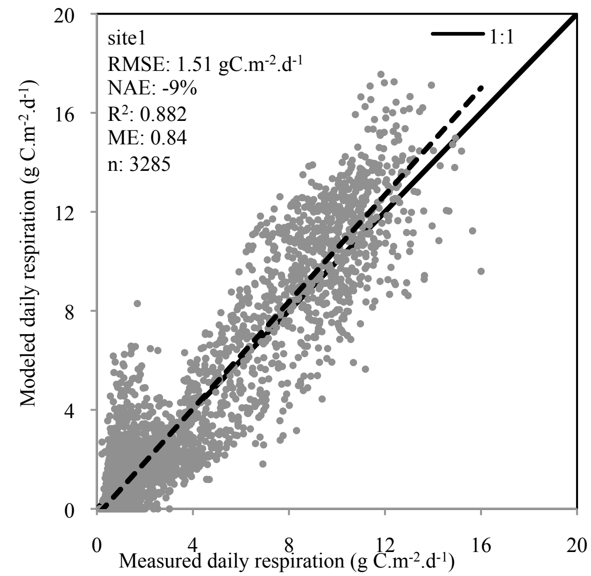


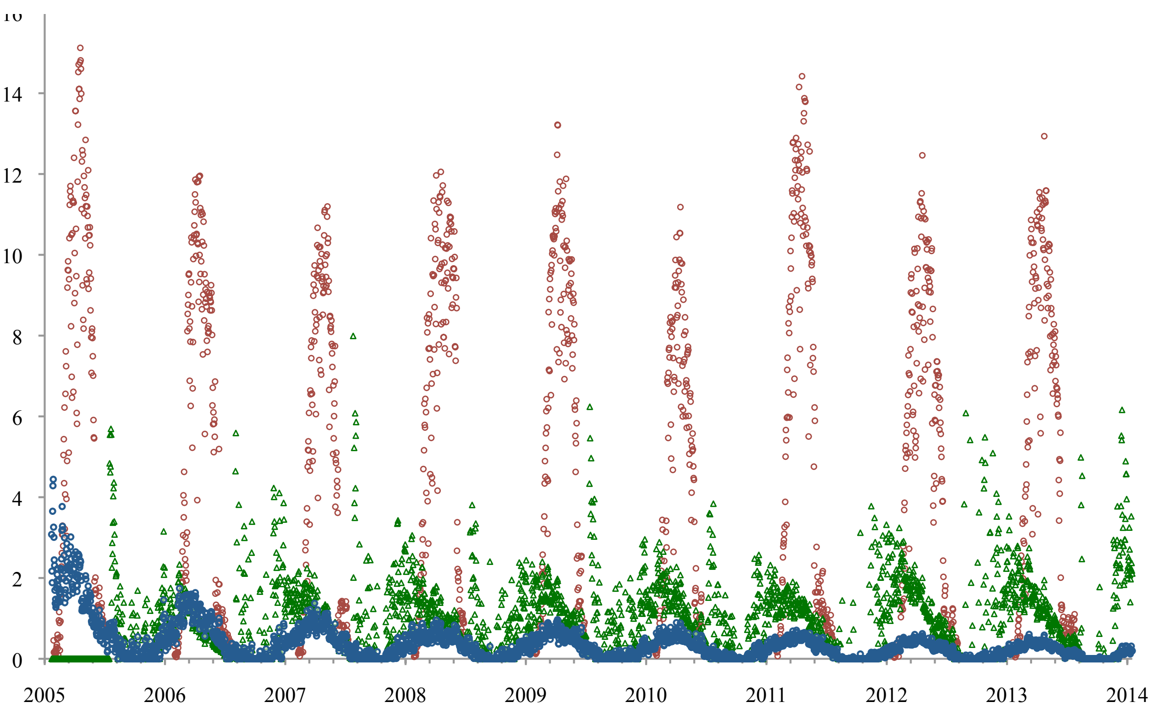
Theoretical cellulosic ethanol, *not efficient/profitable systems currently*

Source: Liska AJ & Perrin RK. 2011. *GIS Applications in Agriculture–Nutrient Management for Improved Energy Efficiency*. CRC Press.

Daily measured CO_2 emissions from continuous maize match models







We know crop residue carbon respires to CO_2

Models for respiration of CO_2 (based on temp. & solar radiation, etc.):

crop (red)

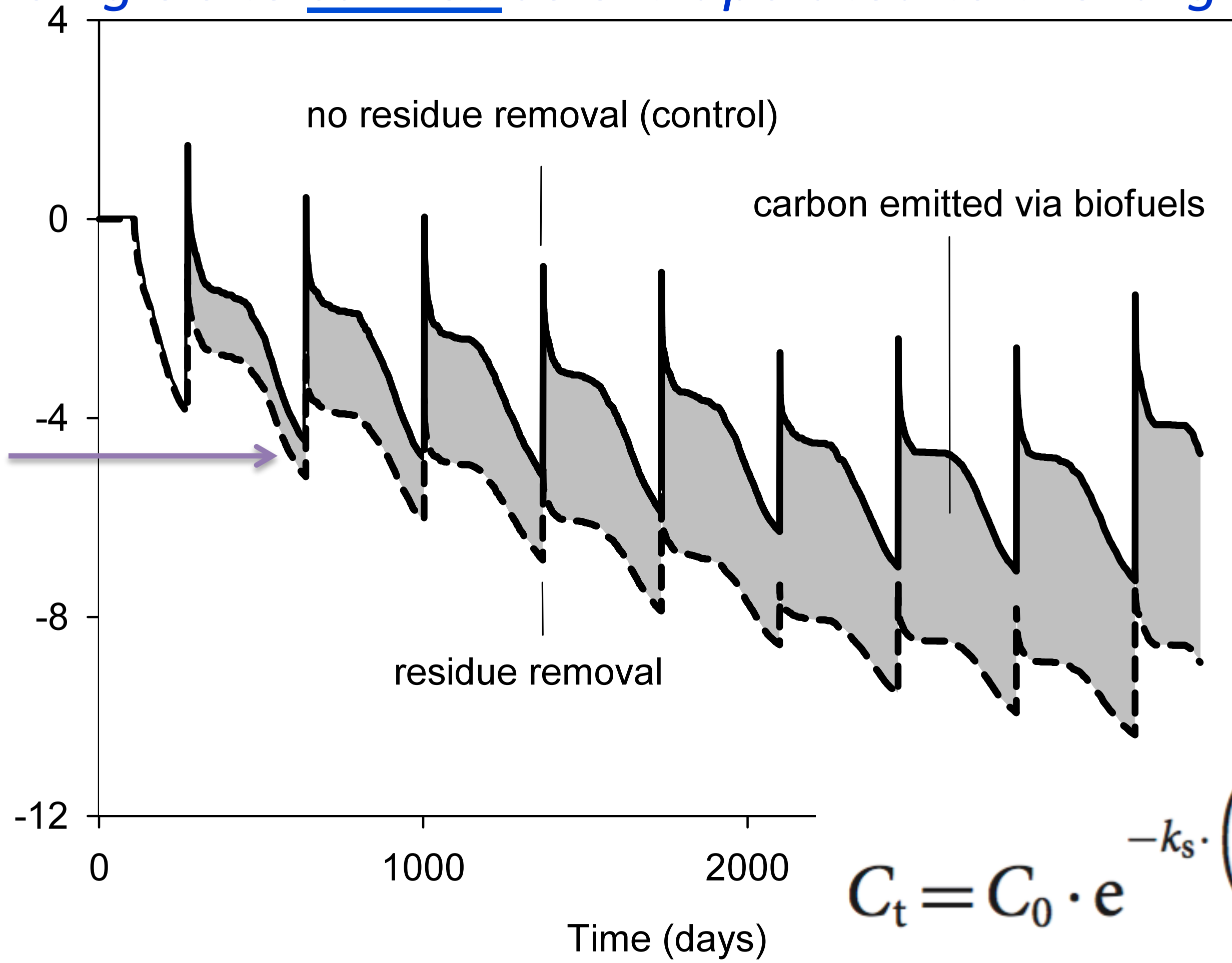
<u>crop residue</u> (green)

soil (blue)

Source: Liska, in preparation

The same multi-pool SOC model quantifies how much carbon is left in **soil & crop residue (continuous maize)** during the same time period *based on measurements of SOC, biomass, temperature in Nebraska; but due to SOC variability, federal researchers asserted these results for a single site cannot be extrapolated to the larger region*

removal of crop residue (6 Mg ha^{-1} yr^{-1}) puts less carbon in the soil

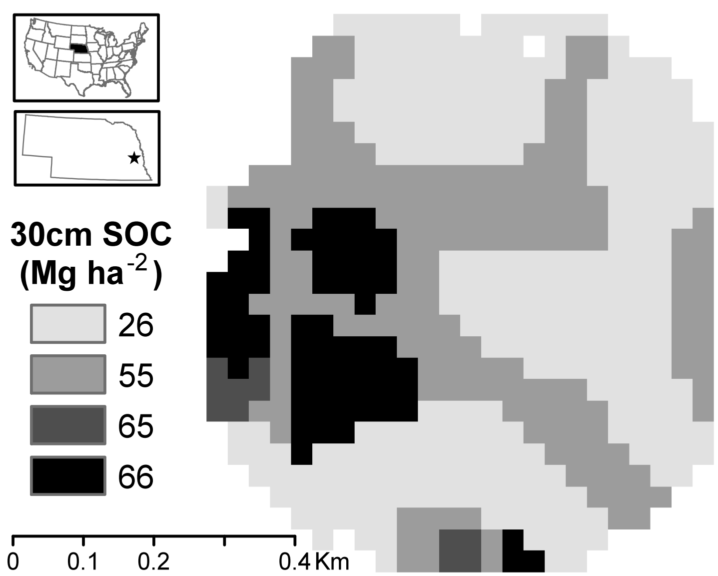


Residue burned as biofuels to CO_2

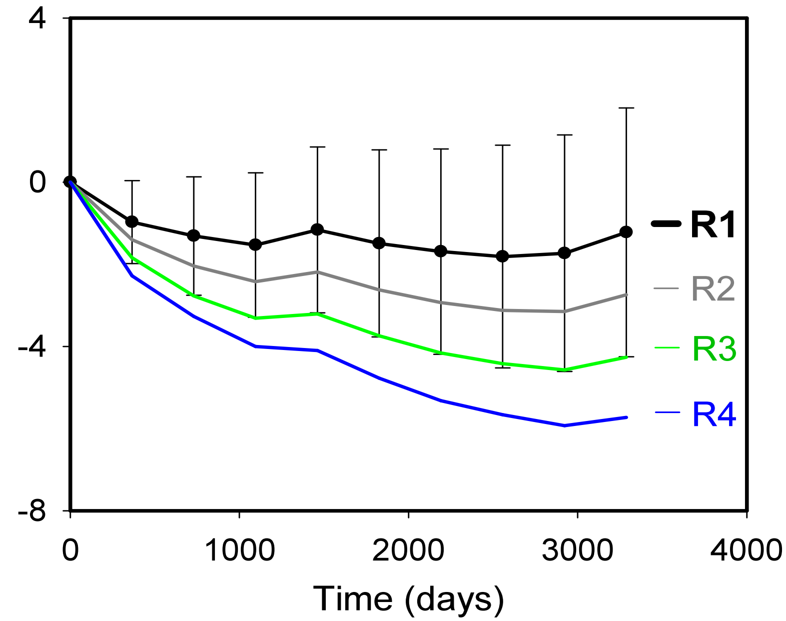
$$C_t = C_0 \cdot e^{-k_s \cdot \left(\Sigma Q_{10}^{\frac{T_a - T_r}{10}} \cdot t\right)^{1-S_s}}$$

Source: Liska et al., *Nature Climate Change* 4, 398-401, 2014.

The soil model was then used with <u>independent</u> geospatial data for SOC, temperature, & maize yields in 4 simulations: R1, R2, R3, R4 (0, 2, 4, 6 Mg ha^{-1} yr^{-1} removal) for each 30 x 30 m cell



Eddy-covariance field site, center pivot irrigation in Nebraska; 48 hectares

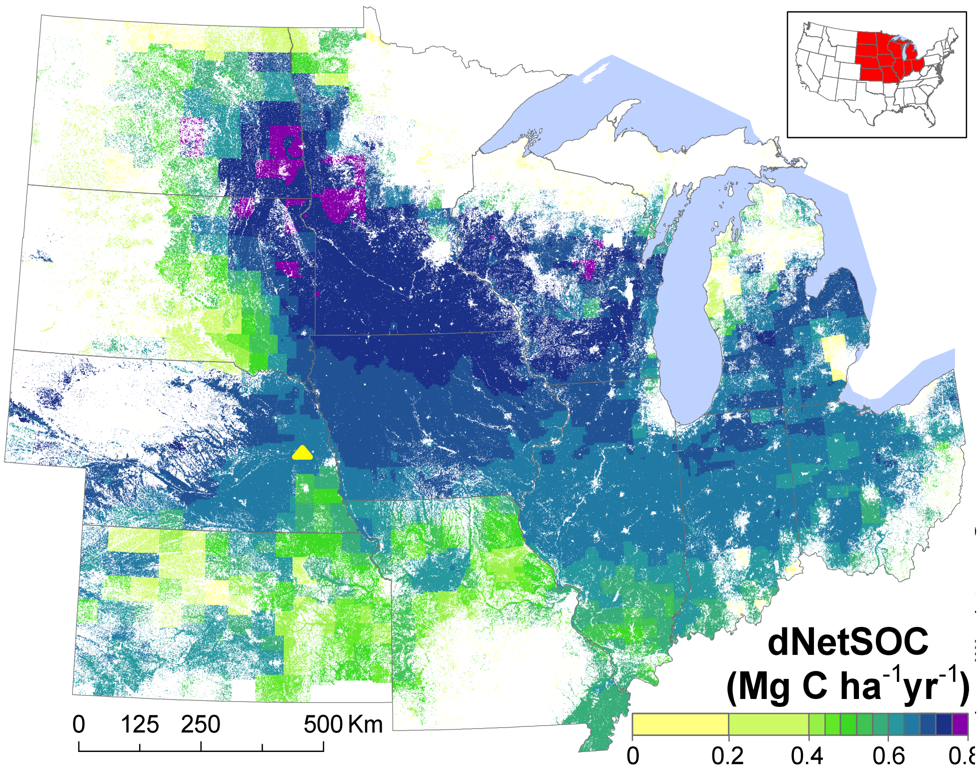


Geospatial modeling finds similar results as field measurements over 9 years, found in previous slide

Source: Liska et al., *Nature Climate Change 4*, 398-401, 2014.

Modeled SOC loss to CO_2 in 'Corn Belt' (maize in central USA) from residue removal

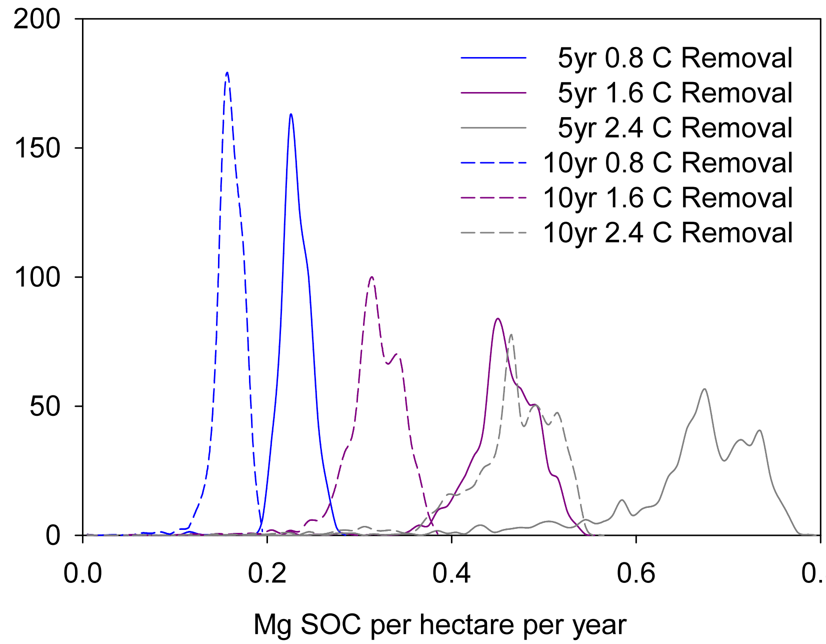
Model applied at 589 million cells, 30 x 30 meters, Supercomputing



Net SOC loss to CO_2 from removal of 6 Mg biomass per hectare per year

Source: Liska et al., *Nature Climate Change* 2014.

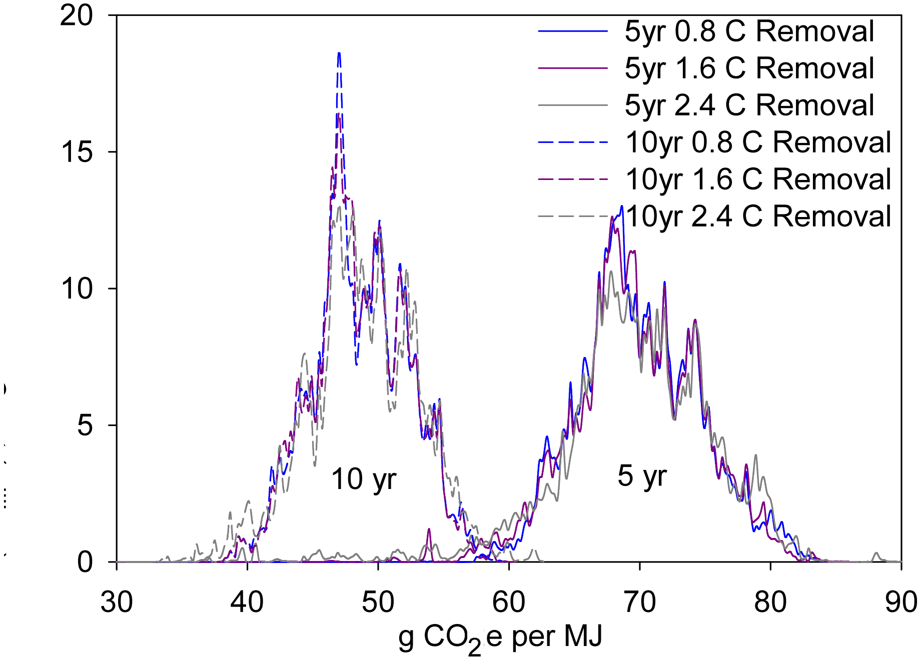
Corn Belt avg. <u>net</u> SOC loss to CO_2 at different removal rates: 2, 4, 6 Mg/ha/yr (589 M cells) (avg. for 5 & 10 years of removal)



<u>More net</u> SOC loss to CO_2 with <u>increased</u> removal of residue, but <u>less loss</u> of SOC over time

Contribution of CO_2 emissions from SOC & crop residue to the life cycle GHG emissions of biofuel, either cellulosic ethanol or thermochemical conversion of maize residue

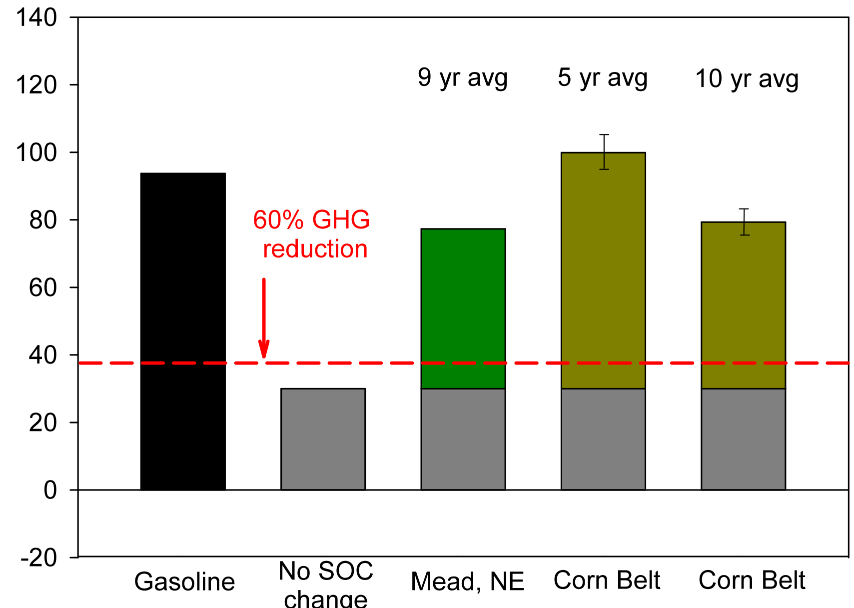
Net CO_2 emissions ***per unit energy*** derived from crop residue ***is constant for all biomass removal levels***



$$\frac{\Delta SOC\text{-}CO_2}{\Delta bioenergy} = \frac{6}{6} = \frac{4}{4} = \frac{2}{2} = \frac{1}{1}$$

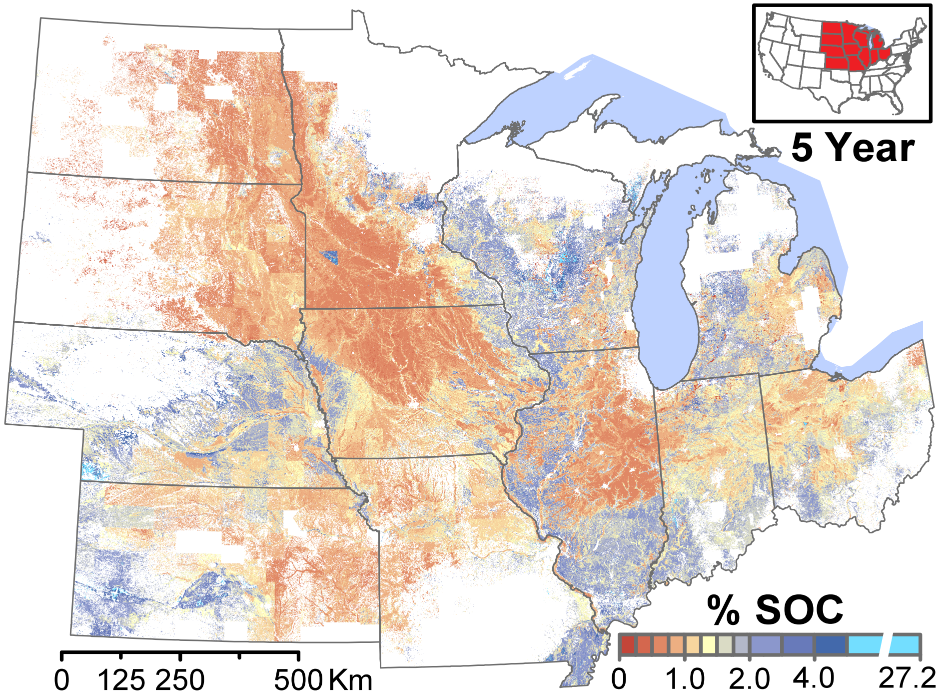
Source: Liska et al., *Nature Climate Change* 2014.

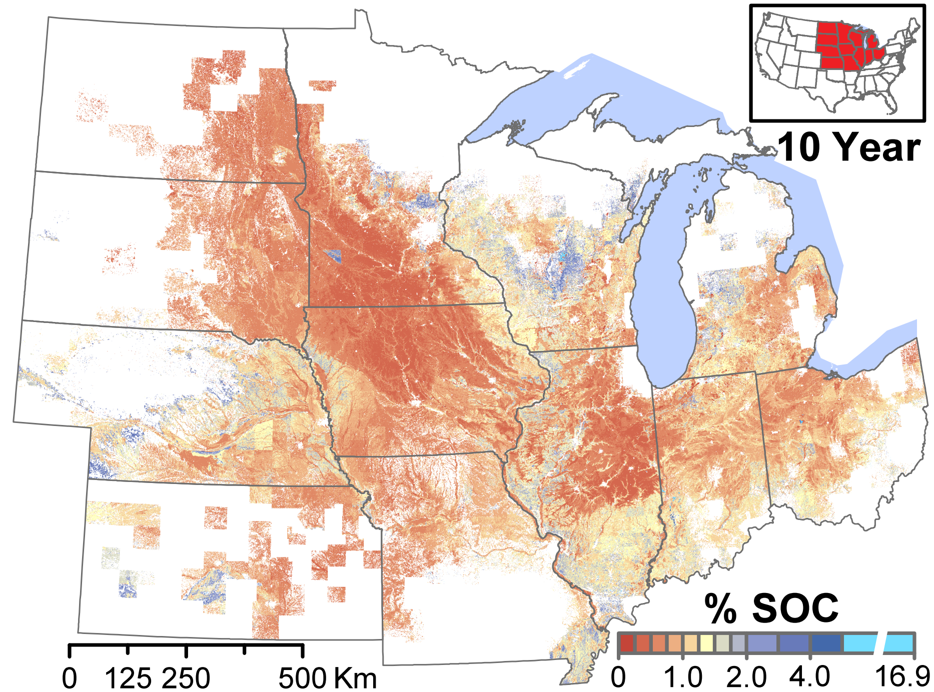
CO_2 emissions from SOC-residue were not previously quantified in LCAs by DOE/EPA



Biofuels from crop residue produce CO_2 emissions ***significantly above US federal standards & gasoline***

Using residue, SOC loss is mostly <u><1% of stock per year</u> over 10 yrs





<1% loss per year is difficult to measure by soil mass, but can be more accurately estimated by CO_2 emissions measurements using eddy flux (Kutsch et al. Cambridge 2009)

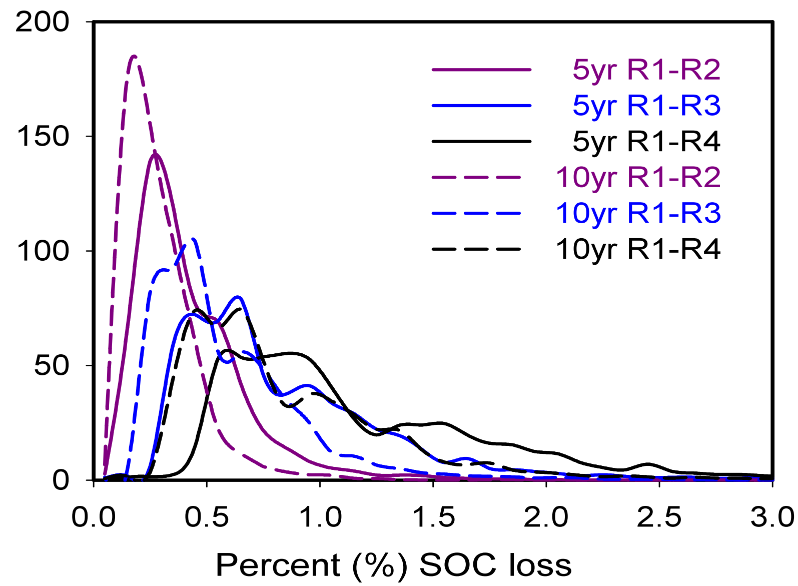
<u>Average initial SOC stock:</u>

74.5 Mg C ha^{-1} 30 cm^{-1} depth

~130 Mg C ha^{-1} 60 cm^{-1}

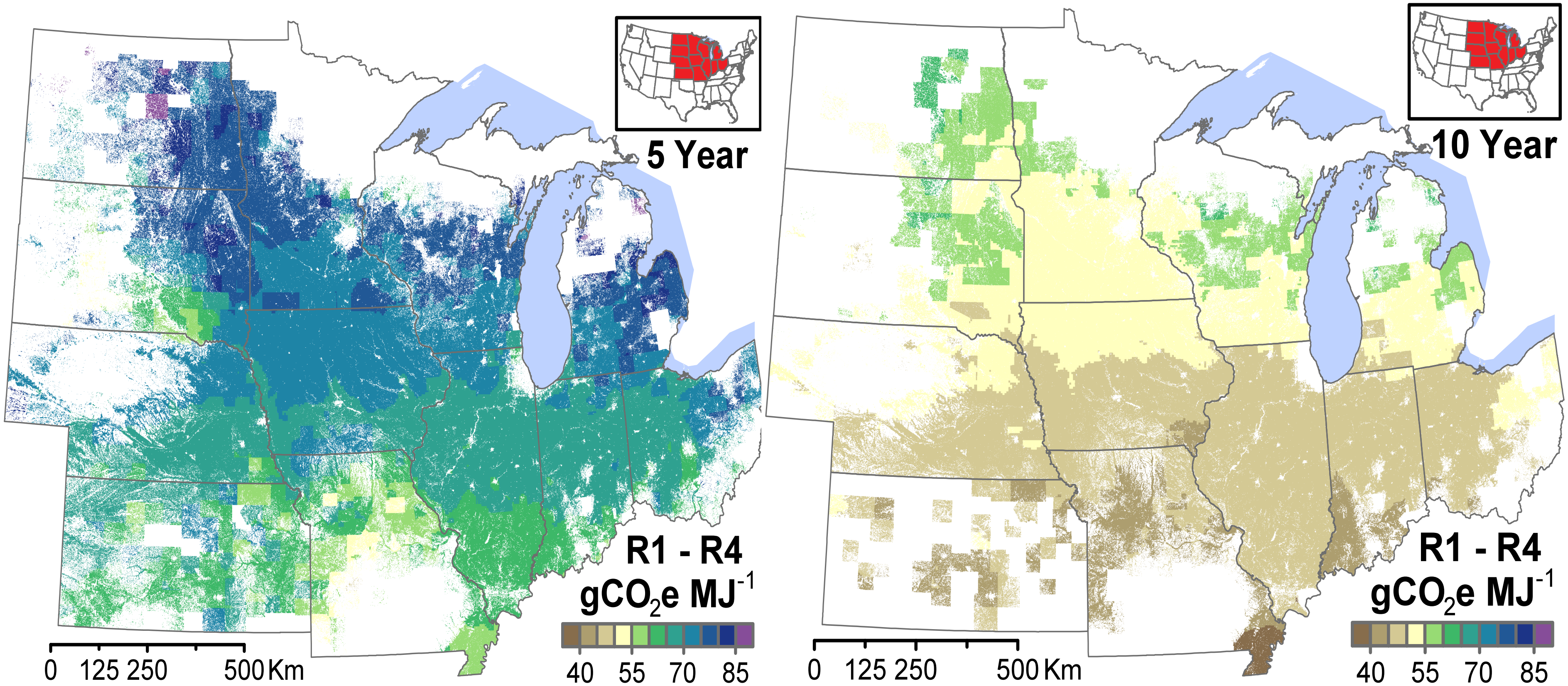
~ 170 Mg C ha^{-1} 90 cm^{-1} (~100 cm^{-1})

(Schmer et al. SSSAJ 2014)



Source: Liska et al., *Nature Climate Change* 2014.

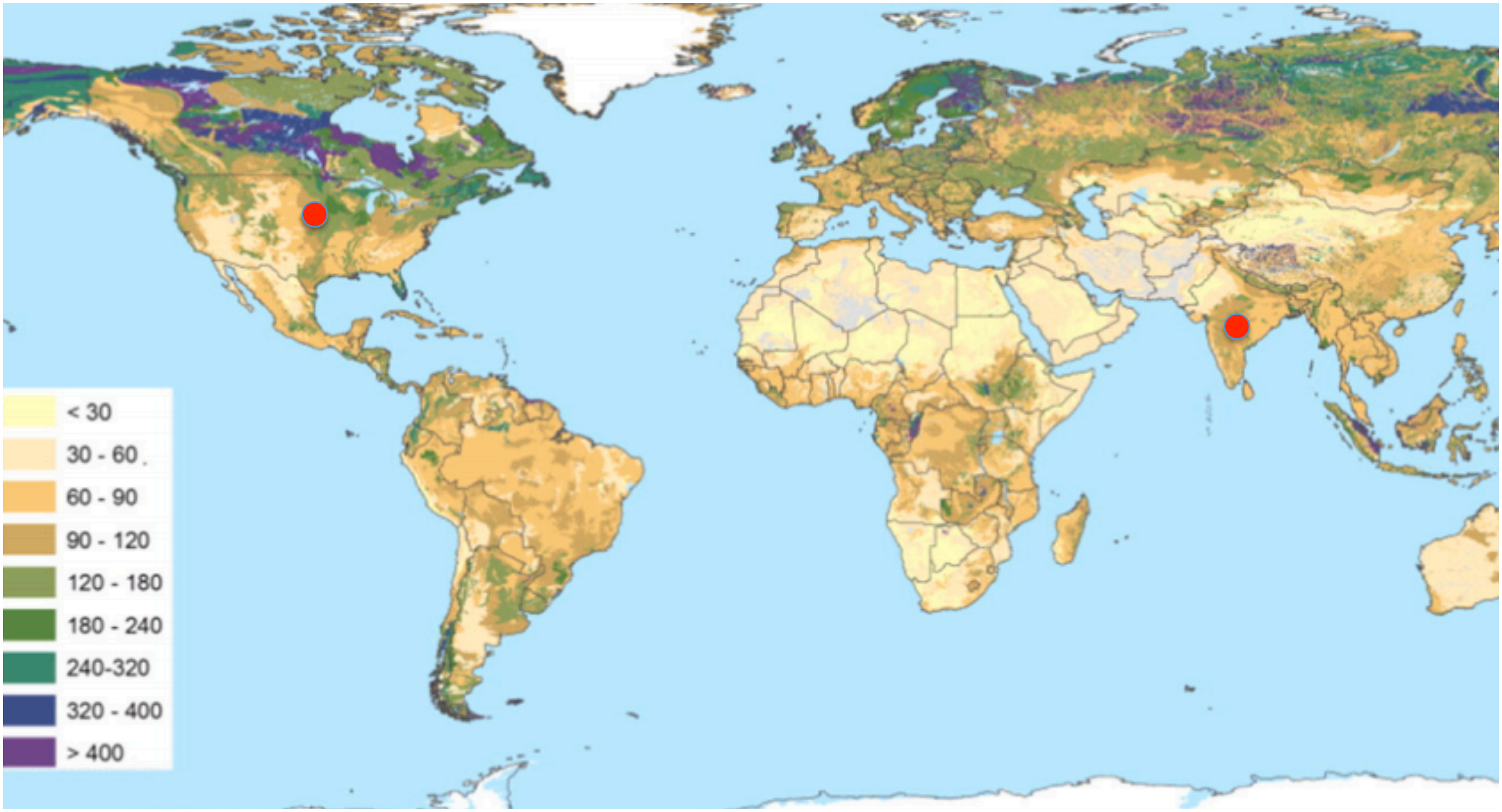
CO_2 emissions from SOC & maize residue are <u>highest</u>
where SOC stock is high (calculated for 30 cm depth),
But removal of *2, 4, or 6* Mg ha^{-1} yr^{-1} gives the same results:
70 ± 6.4 g CO_2 MJ^{-1} (range 30–90) for 5 years
49 ± 4.3 g CO_2 MJ^{-1} (range 33–63) for 10 years
<u>But</u> the EPA has not recognized these results (*The Guardian*, Apr 20, 2014)!



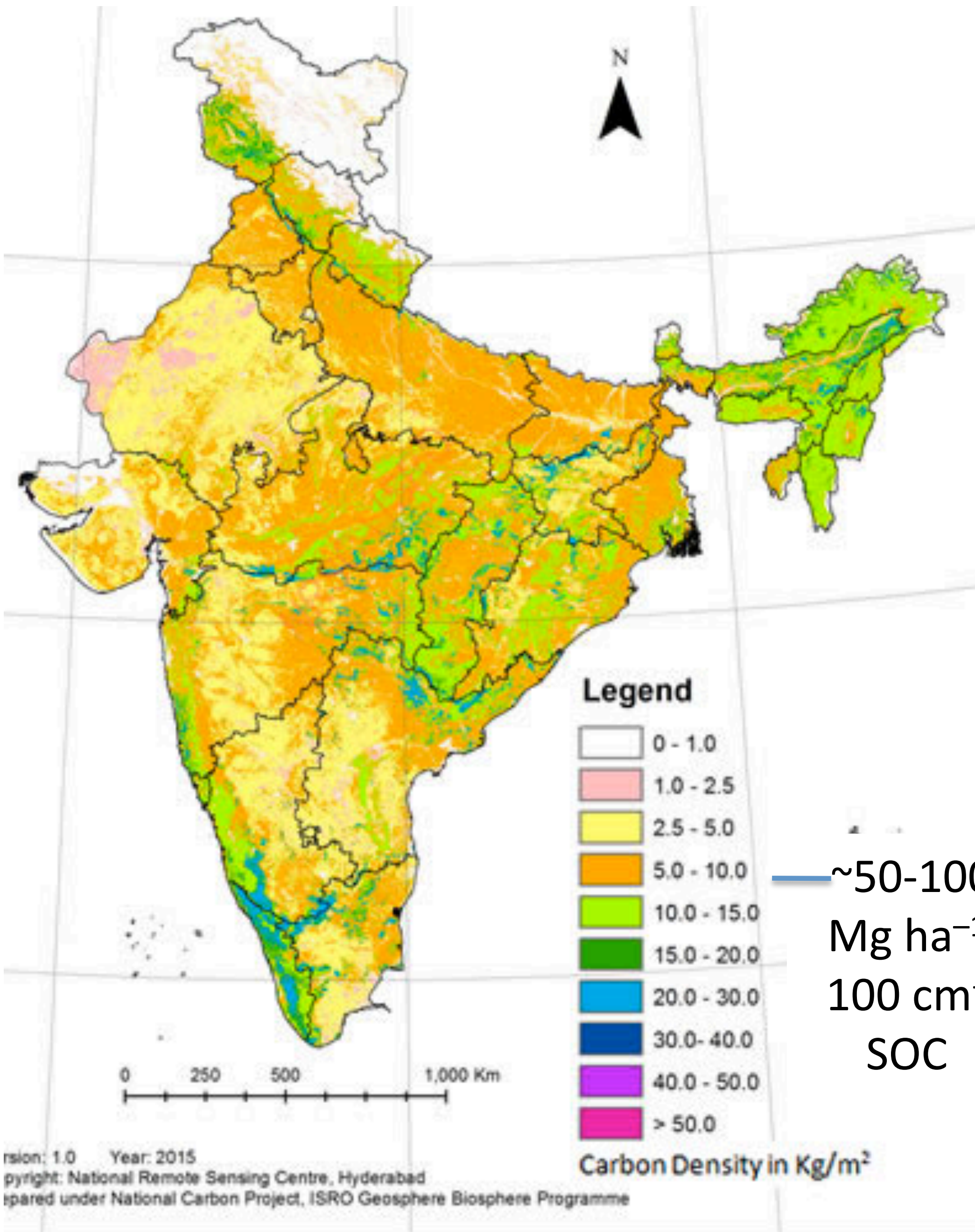
Source: Liska et al., *Nature Climate Change 4*, 398-401, 2014.

Are the US results relevant for India if crop residues are used for biofuels?

Soil organic carbon content to 1 m depth (Mg C ha^{-1})



Source: Batjes, *Geoderma 269*, 61-68, 2016



~50-100 Mg ha^{-1} 100 cm^{-1} SOC

<u>India SOC average (2016)</u> =
69 Mg ha^{-1} 100 cm^{-1}

Most areas have SOC at
~50-100 Mg ha^{-1} 100 cm^{-1}

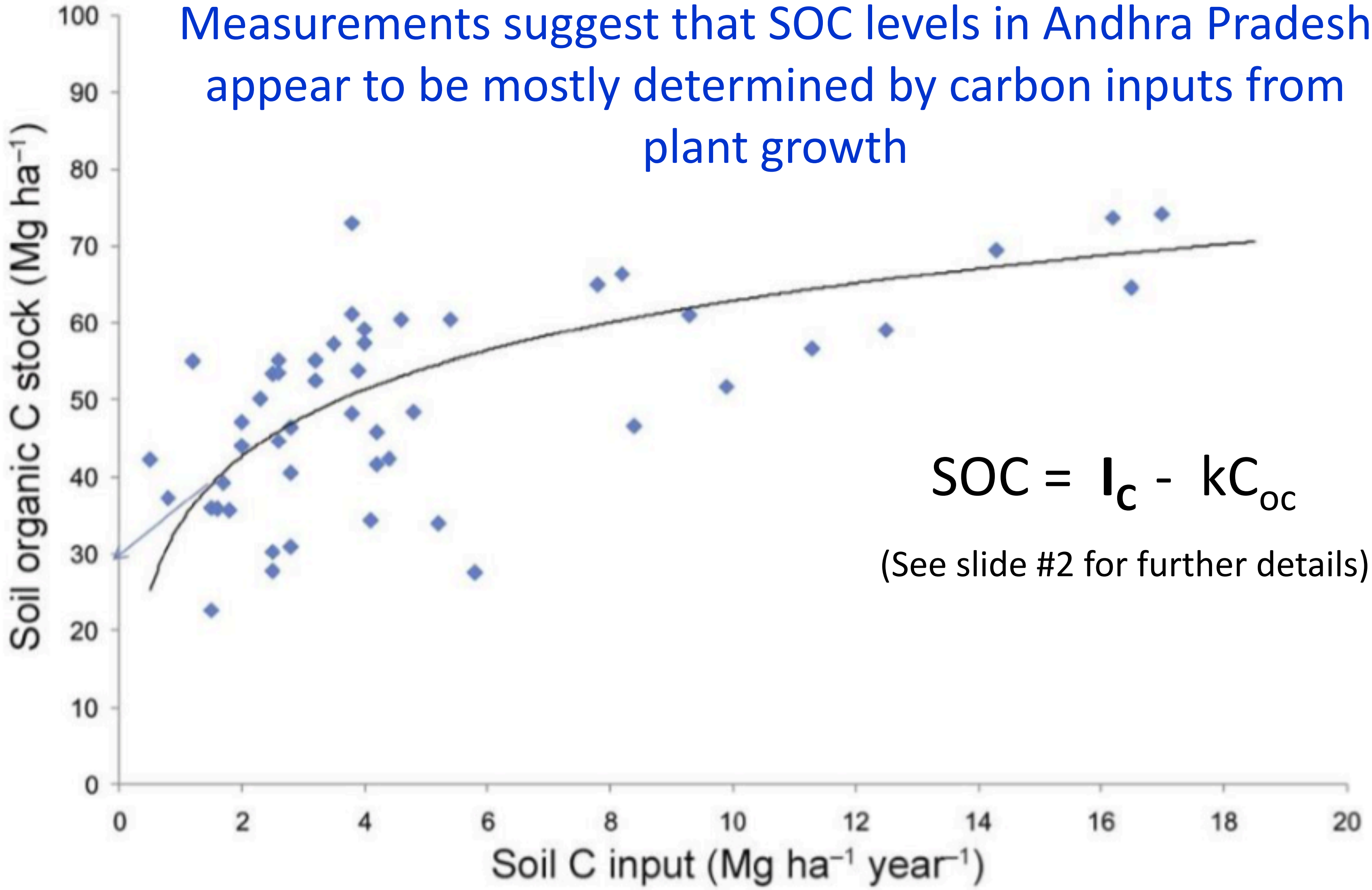
Single crop: **58.5** Mg ha^{-1} 100 cm^{-1}
double crop: **67.4** Mg ha^{-1} 100 cm^{-1}

<u>Andhra Pradesh</u>, India, SOC 60 cm^{-1}
Alfisols, 52.8 Mg ha^{-1} (0.61% OC)
Inceptisols, 51.3 Mg ha^{-1} (0.58%)
Vertisols, 49.3 Mg ha^{-1} (0.54%)
Forests, 87.3 Mg ha^{-1} (0.94%)

<u>Sources</u>: Sreenivas et al. 2016. Digital Organic and Inorganic Carbon Mapping of India, *Geoderma*; Venkanna et al. 2014. Carbon Stocks in Major Soil Types and Land-Use Systems in Semiarid Tropical Region of Southern India. *Current Science.*

https://nrsc.gov.in/Digital_mapping_of_soil_organic_and_inorganic_carbon_status_in_India

Measurements suggest that SOC levels in Andhra Pradesh appear to be mostly determined by carbon inputs from plant growth



$$SOC = \mathbf{I_C} - kC_{oc}$$

(See slide #2 for further details)

Source: Venkanna et al. 2014, *Current Science 106*, 604-611; these findings are further supported by: Lal, 2004, *Science*; Lal, 2006, *Land Degradation & Development*

India's estimated biomass production & potential in 2014 (*Indian government supported study*)

- 39 residues from 26 crops were estimated
- India produces ~686 million tons per year of crop residue
- 234 MT (**34%** of gross) were estimated *as **surplus** for bioenergy generation*; 4.15 EJ, equivalent to **17% of India's total primary energy consumption**
- *Modern bioenergy—biomass conversion technologies (combustion, pyrolysis, gasification, fermentation, anaerobic digestion) for production of heat & electricity, liquid & gaseous transportation fuel, biogas for cooking, etc.*
- **Sugarcane** produces the highest amount of surplus residue followed by **rice**.
- Yet, current crop residue use for livestock feed produces manure which contributes to SOC, but burning biomass would oxidize lignin portion of biomass faster to CO_2, and decrease SOC

Source: Hiloidhari et al. 2014, *Renewable and Sustainable Energy Reviews*.

Estimated CO_2 emissions from SOC and maize residue for biofuels in India

India's lower SOC levels vs US (69 vs. 170 Mg ha^{-1} 100 cm^{-1}), and lower maize yields (~12 Mg ha^{-1} yr^{-1} in Andhra Pradesh vs. ~20 Mg ha^{-1} yr^{-1} *maize* aboveground biomass) means ~50 to 80% as much CO_2 per unit biofuel energy from residue result compared to the estimate for the US:

66% of ~70 g CO_2 MJ^{-1} for 5 years: ~46 g CO_2 MJ^{-1}

= ~half the CO_2 intensity of gasoline: ~92 g CO_2 MJ^{-1}

Location	SOC	g C	Mg/ha	MJ/ha	g/MJ	%
USA	170	1.0	20	10	0.1	100
India	69	0.4	12	6	0.066	66

Source: Liska, April 20, 2017.

More calculations can be done for more robust estimates

Other impacts of increased residue use are perhaps <u>more important</u> issues than C-intensity of biofuels

Increased residue removal would probably have major negative impacts on agricultural productivity:

1) Soil erosion increase (water & wind) = lower crop yields
2) Soil moisture decrease = lower crop yields
3) SOC decrease = nutrient decreases = lower crop yields

R. Lal (2004): *"The close link between soil C sequestration and world food security on the one hand and climate change on the other can neither be overemphasized nor ignored."*

Sources: Lal, 2004, *Science* (The critical limit of SOC concentration for most soils of the tropics is 1.1%; but up to 5.5% has been observed in plantations in India); Lal, 2006, *Land Degradation & Development*

Univ. Nebraska Research Team (*Funding: US Department of Energy*)

Modeling crop & soil CO_2 respiration

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CO_2 Flux Measurements

Prof. Andy Suyker
School of
Natural Res.

SOC Measurements

Prof. Humberto
Blanco-Canqui
Agronomy-Hort

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Geospatial Analysis & Supercomputing

Dr. Maribeth Milner
Agronomy
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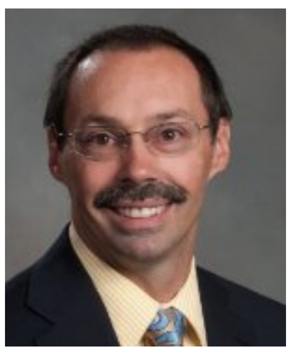

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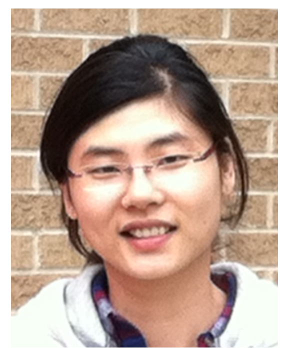

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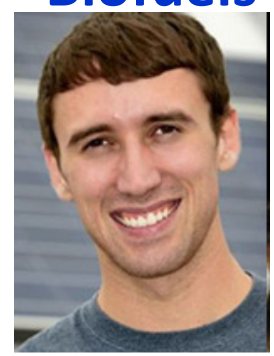
Global Biofuels



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